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Design and Implementation of a Distributed IoT-Based Smart Irrigation System Using LoRa and GSM with Industrial Motor Control

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Abstract

The growing demand for effective water management and sustainable farming practices has led to the development of IoT-based smart irrigation systems. This paper introduces a distributed IoT-based irrigation system that includes two main components: the sensing block and the DOL starter block. The sensing block features an ESP32 microcontroller along with an industrial-grade 7-in-1 soil sensor, ultraviolet sensor, and rain sensor to monitor soil and environmental conditions. Data collected from the sensors is sent to a cloud platform using a 4G LTE GSM module. If there is no network coverage, the data is stored in the internal flash memory and synced when the connection is back. Based on the collected data, control commands are created and sent to the actuator block through LoRa communication technology, which allows for long-range transmission without the need for an internet connection. The actuator block consists of an IoT-enabled Direct On Line (DOL) starter system that controls agricultural motors. Experimental results showed successful communication between the blocks, data logging was completed, and the motor was controlled as expected.

Keywords: Smart Agriculture, IoT, Precision Farming, Soil Monitoring, Irrigation Automation, NPK Sensor, ESP32.

1. Introduction

Agriculture is still a crucial industry for food security worldwide. However, it often faces problems with inefficient water use, limited real-time tracking, and ineffective decision-making in traditional farming methods. Irrigation usually relies on manual control or fixed schedules. These approaches can lead to overwatering, resource waste, and decreased production. IoT technology, along with its digital growth, has become key in creating smarter farming systems. This allows for immediate monitoring and control of the agricultural environment [1].

IoT-driven systems can be implemented into agriculture, where a mixture of distributed sensor networks will be utilized to create soil, weather, and crop status overview. It will enable farmers to practice precision farming. They will monitor moisture content, temperature, and environmental conditions [2].

Furthermore, the deployment of wireless sensor network with cloud computing is an important feature that facilitates the analysis of large amounts of data and decision making on it [3].

Recent studies emphasized that the collocation of the IoT and communications network such as the cellular network or the LPWAN was necessary for the provision of reliable connection especially in rural environments. In particular, GSM and LoRa networks have been widely adopted because of their capability of offering long-distance communication and stable energy consumption [4].

Additionally, the proposed framework will utilize data buffering through internal flash memory in order to shield data during potential network unavailability. Therefore, we can benefit from embedding multiparameter sensor readings, hybrid communication and industrial motor control into a holistic solution for precision agricultural applications.

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2. Related Works

In recent times, researchers have shown growing interest in exploring applications of IoT in the agricultural sector, which are mainly concerned with irrigation, optimization of resource utilization, and enhancement of crop quality. Many literature reviews have been published regarding sensors, IoT, and cloud computing technology for precision agriculture applications. For instance, Dhanaraju et al. presented an extensive review of smart farming using IoT, which utilized the advantages of wireless sensor networks [1]. Also, Abdulhussain et al. examined the current state of the art in sensor technologies and their integration into IoT infrastructures [2].

In addition, the precision agriculture technique has seen progress due to the utilization of big data and wireless communication technologies. According to Alahmad et al., the use of IoT sensors coupled with data analytics not only enhances crop yield and efficiency but highlights the importance of proper communication techniques within IoT agriculture [3]. The latest development in the field is the implementation of IoT irrigation systems that employ the concepts of sensing, cloud computing, and automation in order to achieve efficient water use. [4].

In the last few years, more focus has been made on the application of LPWAN technology, such as LoRa, owing to the fact that this technology is capable of transmitting information at a much greater distance with minimum energy consumption. It has been proven through experience that LoRaWAN-enabled sensing systems perform efficiently as continuous sensors for the environment and plants in agriculture [5]. In addition, Rivera Guzmán et al. developed a LoRa-based sensor network system that could sense different environmental parameters such as soil moisture and UV radiation [6].

Several literatures have examined a comprehensive irrigation system, which makes use of LoRa technology. For example, certain studies carried out recently revealed that it is feasible to construct an irrigation system via LoRa communication, where sensing nodes, cloud-based monitoring, and actuation nodes are utilized to regulate irrigation [7]. Furthermore, Liopa-Tsakalidi et al. developed a LoRaWAN irrigation system, which can be used in larger agricultural fields, making it possible to communicate efficiently while regulating irrigation [8].

Nevertheless, despite the significant advances in irrigation system design that some researchers have achieved, the vast majority of their works are focused on either centralization of architecture or automation of irrigation systems. In addition, very little is known regarding distributed irrigation architecture where the sensors and actuators do not have a direct coupling but rather communicate with each other through long distance communication. Also, there exist some irrigation schemes that cannot operate without an Internet connection.

Considering this problem statement, the current research presents an irrigation system based on IoT architecture with a sensor node and DOL starter node that communicate using LoRa technology.

3. Proposed System

The above mentioned proposed system is developed in such a way that it will be a distributed system with IoT architecture where the main components of this system include two different blocks namely the Sensing block and the Actuation block.

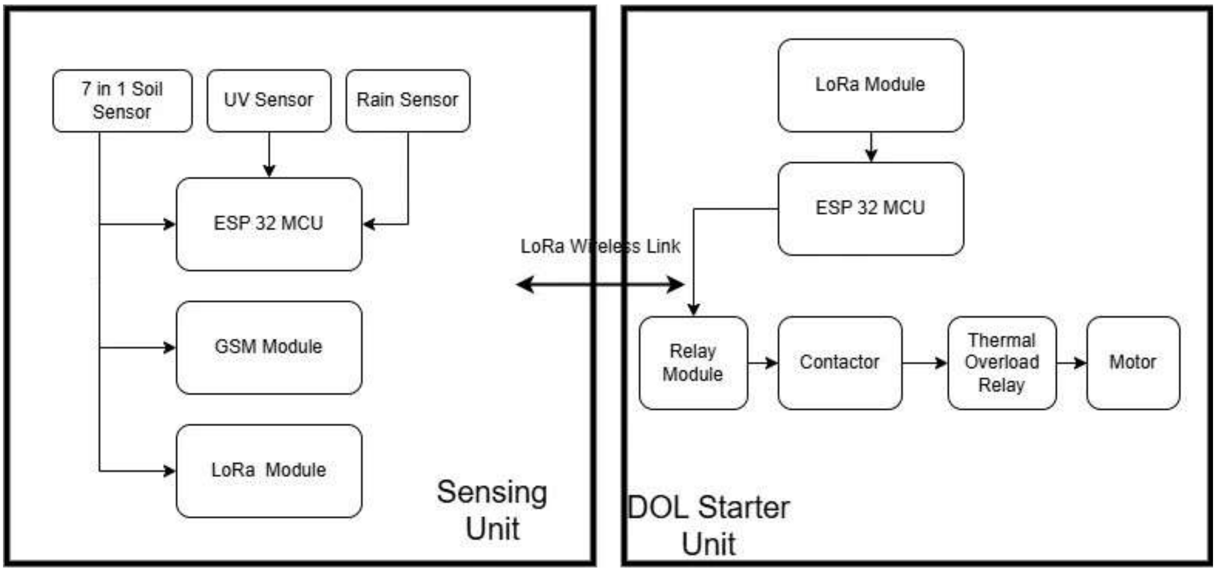

Figure 1: Block diagram of the system

3.1. Sensing Unit

The main function of this module is the real-time monitoring of soil and environmental data using a soil sensor equipped with a 7-in-1 industrial sensor for soil moisture, UV sensor, and rain sensor. They form a very important part in generating data for irrigation because the data generated from them will help us understand the current status of the soil and environment. This data is then processed by the microcontroller ESP32. The processed data is sent to the cloud using the 4G LTE Communication Module with A7670C.

Figure 2: Sensing Unit

3.2. Communication Unit

Decision-making processes related to sensory information and environmental conditions are performed by the sensing unit apart from the connectivity function. These control signals are then transmitted using wireless means employing the LoRa (SX1278) communication module. This LoRa communication technology, which offers high-range transmission capabilities and minimal energy consumption requirements, is suitable for agricultural environments where there is limited connectivity facility..

3.3. DOL Starter Unit

The actuation unit itself has been designed to perform the task of operating the motor control actions of the submerged pump through control instructions that have been sent by the sensor unit. In the designing process of the actuation unit, IoT-based Direct On Line (DOL) starter arrangement has been used. The IoT-based DOL starter arrangement makes use of contactor and relay modules along with the thermal overload relay system.

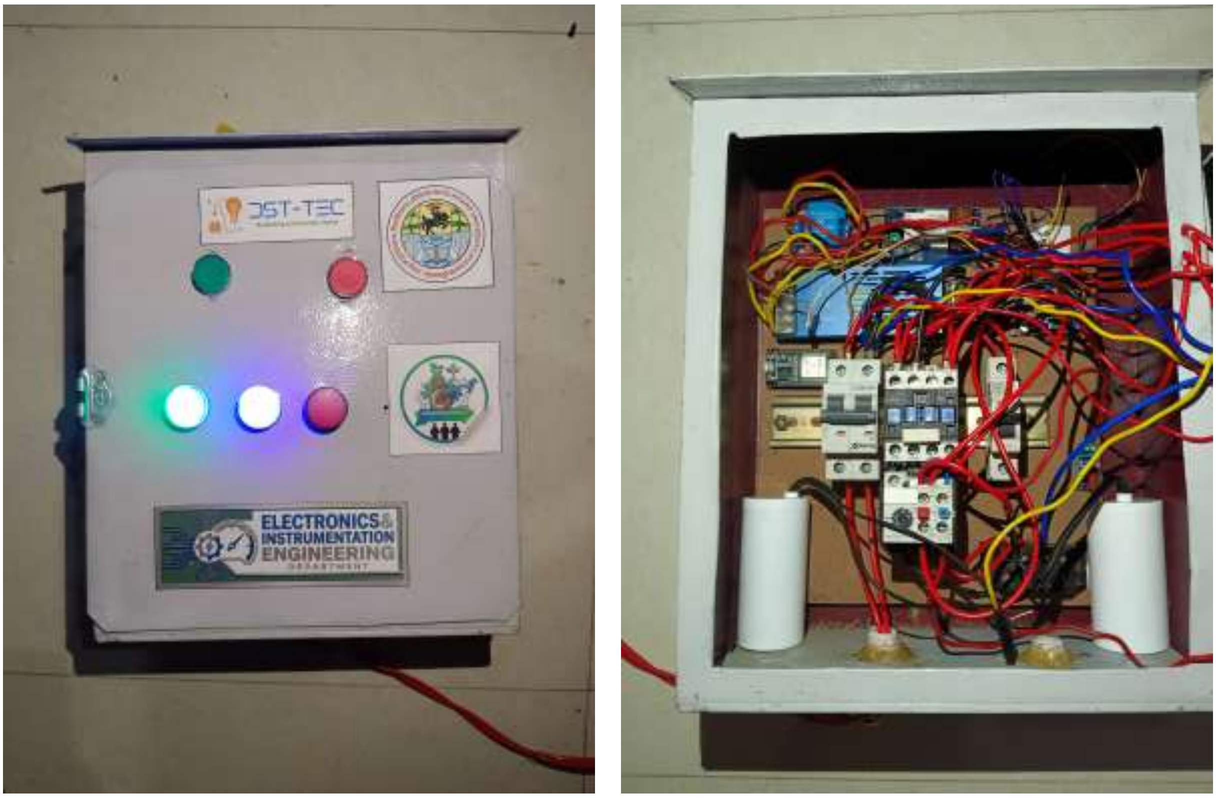

Figure 3: Front and inside views of the DOL starter unit.

3.4. Cloud Platform

Also included in this system is cloud-based monitoring and control through platforms such as ThingSpeak and Blynk. Data gathered from the sensors is transmitted and analyzed in the cloud. Additionally, the Blynk platform makes it convenient for monitoring and scheduling motor control and irrigation activities. In other words, it ensures that the farmer remains in control of activities in the farm.

4. Hardware Components

4.1. ESP32 Micro-controller

The ESP32 microcontroller possesses high-performance capability and low energy consumption and integrates wireless connectivity technologies like Wi-Fi and Bluetooth technology [9]. This microcontroller acts as the processor of the sensing unit and takes charge of collecting data from the sensors, performing calculations, and communicating with the GSM and LoRa modules.

Module of Global System for Mobile Communication (A7670C – VVM501)

The A7670C is a 4G LTE CAT 1 modem that works on different networks such as LTE, GSM, and GPRS [10] providing uninterrupted wireless communication of the data for the Internet of Things. The A7670C is used in the sensor to establish communication with the cloud..

LoRa Module (SX1278) The SX1278 is a low power long range transceiver operating with the LoRa modulation protocol. This module can transmit signals up to several kilometers [11] while consuming an insignificant amount of energy. It is used to send control commands from the sensing unit to the actuation unit to enable the appropriate functioning of the device even in the absence of the internet connection.LoRa Module (SX1278) The SX1278 is a low power long range transceiver operating with the LoRa modulation protocol. This module can transmit signals up to several kilometers [11] while consuming an insignificant amount of energy. It is used to send control commands from the sensing unit to the actuation unit to enable the appropriate functioning of the device even in the absence of the internet connection.

Contactor Contactor refers to a component that is activated using electric signals to control other circuits that require higher power [12]. In the case of the current application, it will be employed in the actuator to control the three-phase motor current.

Relay Module

The relay is essentially a connecting link between the low-voltage ESP32 microcontroller and the high-voltage contactor. It facilitates electrical insulation as well as the operation of the contactor from the microcontroller. The relay plays a critical role in controlling the motor through signal processing.

4.2. Thermal Overload Relay

Thermal overload relay refers to protective relays that protect motors from overheating and overcurrent conditions. This relay detects currents flowing through the motor and disconnects power supplies in case of any abnormalities [14].

4.3. SMPS (Switched Mode Power Supply)

The SMPS is employed for converting AC power supply into regulated DC power supplies. The required DC voltage is needed for supplying power to the control circuit [15]

4.4. Snubber Circuit

Snubber circuit, which is generally an RC filter, is utilized for suppressing the voltage spikes that arise when operating the inductive loads, such as contactor coils [16]. The objective of the circuit is to ensure that the relay contacts and other electronics are not damaged by transients.

4.5. Industrial 7-in-1 Soil Sensor

The sensors used in the system measure NPK, pH, EC, humidity, and temperature values in the soil. The sensors have UART output and high precision because that is necessary to make smart decisions about irrigation in the sensing unit [17].

4.6. UV Sensor

The UV sensor detects the intensity of solar radiation, influencing evapotranspiration and growth rates of plants [18]. The present case study involves this sensor, providing environmental inputs useful for intelligent irrigation recommendations.

4.7. Rain Sensor

The rain sensor can be considered as an environment sensor to avoid unnecessary watering [19]. This type of sensor plays a very significant role in the process of smart irrigation because of its intelligence.

4.8. DOL Starter Unit Circuit

The Submersible motor control has been achieved using a DOL starter setup that utilizes
IoT. The DOL starter unit comprises a contactor, thermal overload relay, relay modules, and pushbuttons for start and stop functions. There are different ways to control the device, such as manually, remotely through the use of mobile application, and wirelessly using the LoRa module. The incorporation of IoT technology in a traditional DOL starter allows for efficient Submersible motor control in an industrial setting.

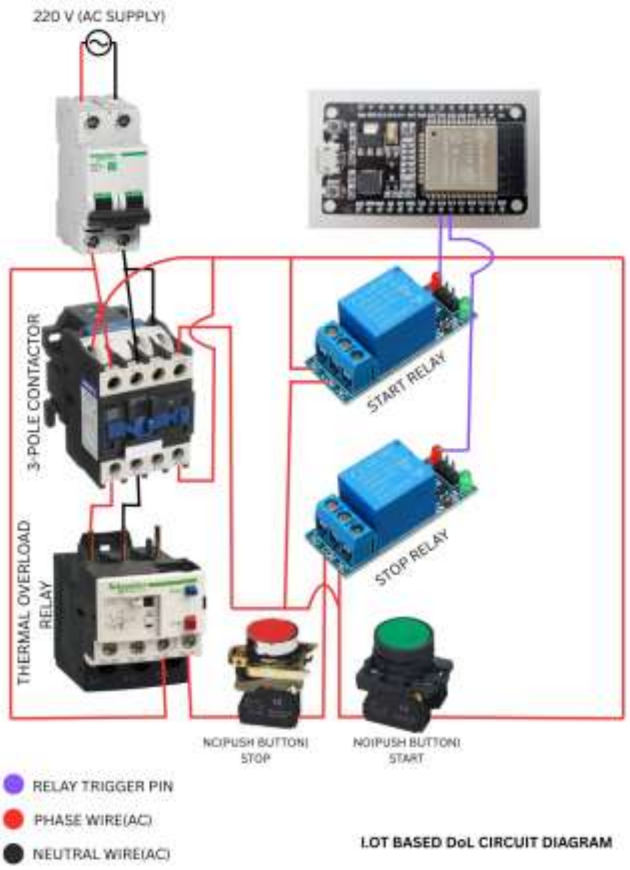

Figure 4: Direct-On-Line (DOL) Submersible motor control circuit

5. Result and Discussion

Testing was done on the proposed system to measure the extent of communication, functionalities of the motor control system, and efficiency of data transfer. Various sub-systems, such as the IoT control, GSM communications, LoRa communication, and motor functionality, have been tested inside and outside the laboratory.

The functionalities of the remote motor control were first tested using the Blynk application. This made it possible to control the Submersible Motor to switch ON and OFF using the mobile phone application. The speed of action from the mobile phone to operation of the motor proved fast, making it efficient to control the Submersible Motor using both mobile phones and cloud-based controls. In addition, testing was also done on the manual controls using push buttons. It was evident that the system could switch between IoT and manual controls.

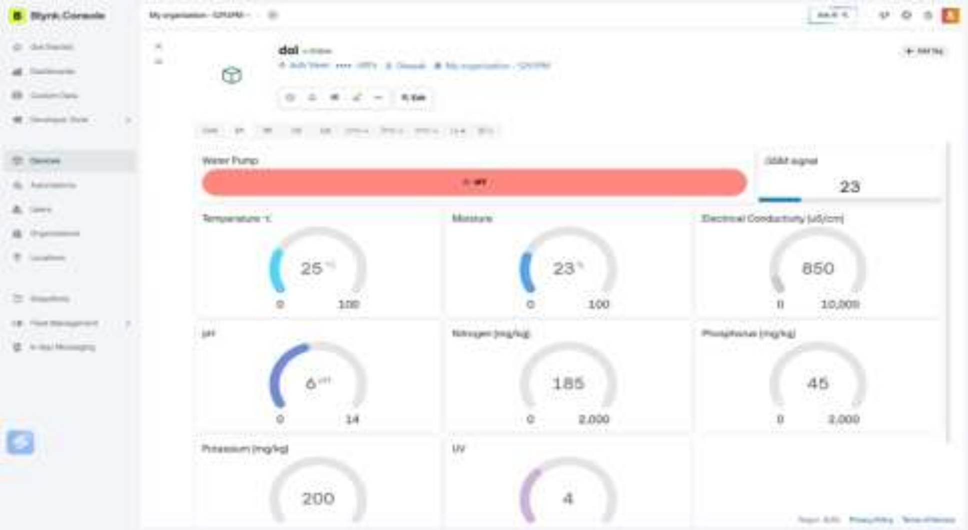

Figure 5: Blynk application dashboard showing Submersible motor control buttons

Data transmission capability through the cloud network was achieved using the ThingSpeak software program. Sensor data concerning soil properties and environmental data were transmitted and displayed in real-time through the application. It is important to state that no delays or updating of data were experienced. Real-time data logging enables analysis and assists decision-making on irrigation practices.

Figure 6: Soil moisture trend over 24 hours as displayed on Thingspeak

The test on the submersible motor controller subsystem was carried out using a 1HP motor for agriculture through the Direct On Line (DOL) starter method. In this case, the submersible motor was effectively operated using the switching process that made use of the contactor that was activated by the relay. The startup and shutdown processes were successfully performed using both the manual and remote control techniques.

Figure 7: Testing of submersible motor at farm

In addition to this, the performance of the LoRa communication network was evaluated by analyzing the changes in SNR and RSSI with respect to distance, as shown in Figure 8. For this purpose, one of the nodes was fixed while the other was moved away from it. The position of the moving node was identified by the Neo-6M GPS module with an expected error margin of 2.5 meters. The distance between the two nodes was calculated using the Haversine formula. The communications were performed by using the helical antenna included in the SX1278 module kit without any changes in antenna configuration.

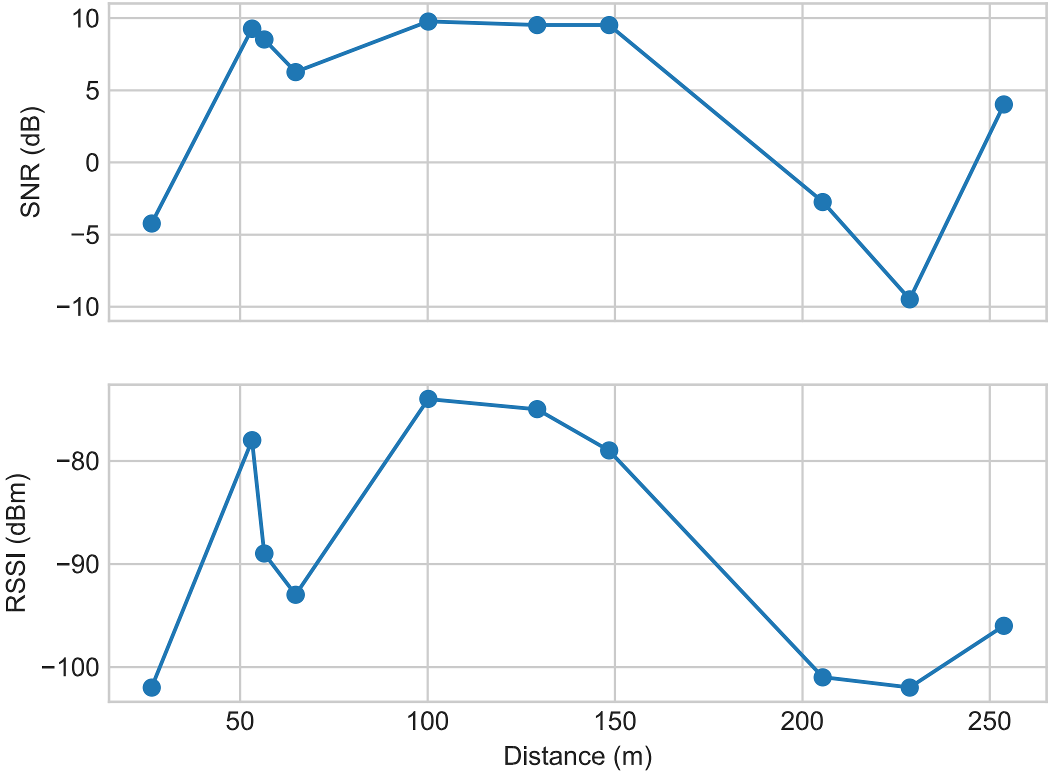

Figure 8: LoRa Distance Test

From the results, it is clear that the LoRa transceivers could maintain successful communications within a distance of about 200 m. The SNR and RSSI readings for this distance showed satisfactory values, allowing effective data transmission. However, beyond 200 m, the quality of the signal started deteriorating significantly, leading to unsuccessful communications.

6. Conclusion

A framework has been presented for the design and implementation of a distributed IoT irrigation system with parameter sensing, hybrid communications, and industrial motors at the prototyping level. This irrigation system includes a sensing unit comprising ESP32, 7-in-1 industrial soil sensor, UV sensor, and rain sensor for sensing environment parameters along with a 4G LTE GSM module for transmitting data to the cloud server. Control signals are sent to the starter box and control the electric motor via the DOL starter unit using the LoRa communication technology.

The results obtained from the experiment indicate the efficiency of transferring the cloud data, remote controlling of the motor, and the reliable communication through LoRa technology in the defined distance. The use of flash memory during the transfer of information acts as the buffer that prevents possible losses of data due to the internet connection problem.

The major advantage of the proposed system is its distributed design, which makes the system flexible and scalable, presence of industrial equipment, such as contactor and thermal overload relay to provide reliable operation of the system, as well as hybrid type of communication using both GSM and LoRa.

However, there are certain drawbacks in this model too. As of now, the model has been used for testing in prototype form only and has not yet been installed in practical environments on a large scale basis. The efficiency of communication may very well depend upon the environment within which the model is used, particularly in the event that there are obstacles present. Lastly, at present, the model uses rule-based decision making and not automatic irrigation control.

Improvement for the future would include the large-scale implementation of the system and analysis of its efficiency under different agriculture-related environments. Machine learning can be employed in estimating the need for irrigation and fertilizer applications. Employing other sources of energy, like solar energy, is another potential approach.

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